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An International Research Conference on
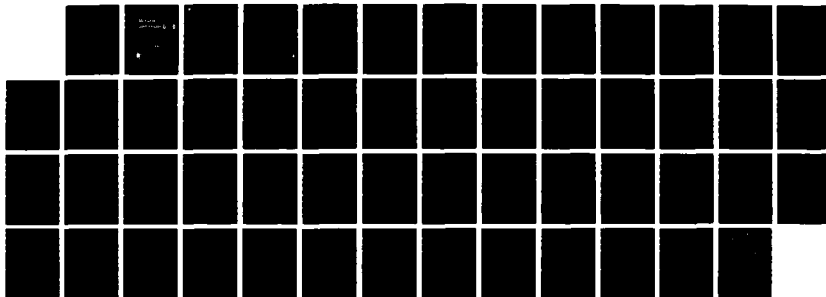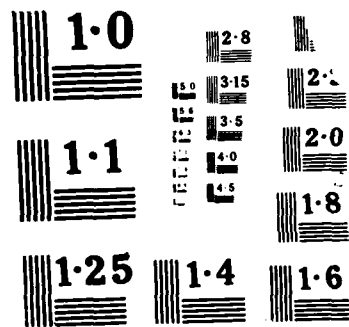
Reliability and Quality

June 9-11, 1986

UNIVERSITY OF MISSOURI
Columbia, Missouri

Abstracts

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A conference on reliability and quality was held at the University of Missouri from June 9-11, 1986. At least 112 attendees heard presentation by leaders in academia, industry, and government. There was ample time for informal discussion of research issues revised at the conference.

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PROGRAM

MONDAY, JUNE 9, 1986

A.M.

8:00 REGISTRATION   Ellis Auditorium Foyer

8:30 WELCOME

Milton Glick
Dean, College of Arts & Science
University of Missouri-Columbia

SESSION I   Ellis Auditorium
Chair: W. A. Thompson, Jr.
University of Missouri-Columbia

8:45   The Role of Statistics in Industry
       G. E. P. Box
       University of Wisconsin-Madison

9:30   Statistical Problems in Developing   uter
       Aided Engineering Methods for Designing
       Quality and Reliability into Products
       Jeff Hooper
       AT&T Bell Laboratory

10:00 COFFEE

SESSION II
Chair: Max Engelhardt
University of Missouri-Rolla

10:30 Repairable Systems Reliability: Research
       Topics and Presentation of Research
       Results ,
       Harold Ascher
       Naval Research Laboratory

11:00 Linking LOR Models to Provisioning Models
       Melvin B. Kline
       Naval Postgraduate School

11:30 Cumulative Damage Threshold Crossing
       Models
       J. Sethuraman* and Thomas R. Young
       Florida State University

12:00 LUNCH   Memorial Union
                                            N 214/215

* Will present paper

<div align="center">

SESSION III   Ellis Auditorium
Chair: W. Golomski
Golomski & Associates

</div>

P.M.

1:30   An Investigation of Parameter Design
Optimization
C. F. Jeff Wu
University of Wisconsin-Madison

1:55   A Geometric Representation of Taguchi
Signal to Noise Ratio
Khosrow Dehnad
AT&T Bell Laboratories

2:20   Measuring Variation for Quality Control
Applications
David M. Rocke
University of California-Davis

2:40   Systematic Arrangements of Taguchi Lattices
Peter W. M. John
University of Texas-Austin

3:00   COFFEE

<div align="center">

SESSION IV
Chair: Major B. Woodruff
Air Force Office of Scientific Research

</div>

3:30   Bayesian Test Design for Bernoulli Processes -
An Application
Major Buddy B. Wood
Air Force Center for Studies and Analyses

4:00   On A Minimal Repair Model and Some
Prediction Results
Ramesh C. Gupta* and S. N. U. A. Kirmani
University of Maine and University of Northern Iowa

4:30   Some Recent Results on Accelerated Life Testing
A. P. Basu
University of Missouri-Columbia

8:00   WELCOME PARTY   Broadway Inn

SESSION V   Ellis Auditorium
Chair: P. Shaman
University of Pennsylvania

A.M.

8:00   Nonparametric Procedure for Selecting
        the Least NBU Population; Large Sample
        Approach
        Dong Ho Park and K. M. Lal Saxena*
        University of Nebraska-Lincoln

8:15   Influential Nonnegligible Parameters Under
        the Search Linear Model
        Subir Ghosh
        University of California-Riverside

8:30   Issues Related to the Reliability of
        Production Equipment
        Robert H. Lochner
        W. A. Golomski & Associates
        /Field

8:45   Statistical Techniques for Combining
        Laboratory and ~~Full~~ Experiments for an
        Environmental Stress Model of Series Systems
        John P. Klein and Sukhoon Lee*
        The Ohio State University

9:00   Approximate Computation of Power
        Generation System Reliability Indexes
        M. Mazumdar and C. K. Yin*
        University of Pittsburgh

9:15   Statistics - A Tool for Quality and
        Productivity Improvement
        S. Sengupta
        Honeywell, Defense Systems Division

9:30   Some Asymptotic Problems in Reliability
        Theory
        J. K. Ghosh
        Indian Statistical Institute, Calcutta, India

9:45   Estimation of the Intensity Function of
        a Weibull Process
        Steven E. Rigdon and A. P. Basu*
        Monsanto Research Corporation and
        University of Missouri-Columbia

10:00   COFFEE

SESSION VI   Ellis Auditorium
Chair: D. DePriest
General Electric

A.M.

10:30   Introduction to Failure Mode Strategy and
          Effectiveness Factors
          Larry H. Crow
          AT&T Bell Laboratories

11:00   Practical Issues in Reliability Analysis
          Kieron A. Dey
          IIT Research Institute

11:30   Estimating Jointly System and Component
          Life Distributions Using a Mutual
          Censorship Approach
          Hani Doss*, Steve Freitag and Frank Proschan
          Florida State University

12:00   LUNCH   Memorial Union
                                             N214/215

SESSION VII   Middlebush Auditorium
Chair: M. Krier
Eastman Kodak

P.M.

1:25   Multivariate Quality Control in 1986
          J. Edward Jackson
          Consultant

1:55   The Use of Multivariate Control Charts
          William H. Woodall
          The University of Southwestern Louisiana

2:25   Average Run Length Comparisons of Two
          Multivariate Cusum Charts for Controlling
          the Mean of Multivariate Normal Processes
          Joseph J. Pignatiello, Jr.* and George C. Runger
          The University of Arizona and IBM

2:45   Quality Control Charts with Points
          Replaced by Box-Plots
          Boris Iglewicz
          Temple University

3:00   COFFEE

SESSION VIII
PANEL DISCUSSION

P.M.
3:30–5:00   *Nancy Mann (Chair)*
University of California-Los Angeles

R. Hannula
General Electric

Larry Crow
AT&T Bell Laboratories

R. Launer
Army Research Office

B. Perry
McDonnell Douglas

6:30	SOCIAL HOUR	Joan's on Ninth
7:00	BANQUET	Joan's on Ninth

Major Thrust on the ASA Productivity and
Quality Committee
Blan Godfrey
AT&T Bell Laboratories

WEDNESDAY, JUNE 11, 1986

SESSION IX   Ellis Auditorium
Chair: Jim Higgins
Kansas State University

A.M.
8:15   The Interrupted Revival Process Reliability
Model for a Maintained System
Michael Tortorella
AT&T Bell Laboratories

8:30   Hazard Functions and Generalized Beta
Distributions
James B. McDonald* and Dale O. Richards
Brigham Young University

8:45   Parameter and Tolerance Design in
Quality Design
A. Winterbottom
The City University, London, England

9:00   Fault Tolerant ICs: Endurance of
EEPROMs Utilizing On-Chip ECC
Tim Haifley
SEEQ Technology, Incorporated

9:15   Establishing Specification Limits for Raw
Materials in Chemical Processes by Combining
Traditional RSM or EVOP with Taguchi Style
Outer Arrays
John Lawson
FMC Corporation

A.M.

9:30   Models for Reliability Performance and
Costs: An Application to Structural
Design Alternatives
Andrea L. Long
University of Michigan

9:45   COFFEE

SESSION X
Chair: M. Shaked
University of Arizona

10:05   Research Opportunities in Software Reliability
John D. Musa
AT&T Bell Laboratories

10:45   Reliability Prediction as a Tool for
Software Development
Michael Dyer
IBM Federal Systems Division

11:25   Software Productivity Measurement
Sailes K. Sengupta* and Sushovan Sen
South Dakota School of Mines & Technology

SESSION XI
CLOSING REMARKS

11:40   *Blan Godfrey and Larry Crow*
AT&T Bell Laboratories

CONFERENCE ADJOURNED

REPAIRABLE SYSTEMS RELIABILITY:
RESEARCH TOPICS AND PRESENTATION OF
RESEARCH RESULTS

Harold Ascher
Naval Research Laboratory
Washington, D. C. 20375-5000

Twelve research topics for repairable systems are presented in Ascher and Feingold (1984, Chapter 9). These will be discussed, as will the preparation and/or updating of 5 Military Handbooks dealing with such systems. Great stress will be placed on how research results should be presented. There is just enough similarity between the modeling/analysis of nonrepairable and repairable sytems's failure data to make it essential to emphasize the major differences between the two situations. The past overemphasis on the tenuous similarities has resulted in widespread confusion about basic - and inherently simple - concepts, cf. Easterling (1985).

References

H. Ascher and H. Feingold (1984). "Repairable Systems Reliability: Modeling, Inference, Misconceptions and Their Causes," Marcel Dekker, New York.

R. Easterling (1985). Review of A&F (1984) in Technometrics, Vol. 27, No. 4, pp. 439-440.

SOME RECENT RESULTS ON ACCELERATED LIFE TESTING

A. P. Basu
University of Missouri-Columbia
Columbia, Missouri

In this paper a survey of some recent results on accelerated life testing is given.

Parametric accelerated test, when there are multiple failure modes are first given. Nonparametric approaches to th's problem in the presence of censored data are then discussed. Finally we consider the case of a two-component system where component lifetimes follow the bivariate exponential distribution of Marshall and Olkin.

THE ROLE OF STATISTICS IN INDUSTRY

G. E. P. Box
University of Wisconsin
Madison, WI

Here some ideas of Taguchi on data analysis, signal to noise ratio, etc. are discussed. Objectives, usefulness, efficiency and robustness of the concepts are considered. Finally, an alternative approach is presented.

INTRODUCTION TO FAILURE MODE STRATEGY AND EFFECTIVENESS FACTORS

Larry H. Crow
AT&T Bell Laboratories

The initial prototypes for a complex system will generally have reliability problems which must be found and fixed through a development test program. The system will enter development testing at an initial reliability value. As problems are found during test and corrected, the reliability will grow from this initial value toward the system growth potential. The growth potential for a system design is the maximum system reliability that can be attained for a particular management strategy. This is the value that is usually estimated with a reliability prediction. The management strategy toward reliability places failure modes into two categories, Type A and Type B. Type A modes are all failure modes such that when seen during test, no corrective action will be taken. The Type A group will include, for example, mature components and subsystems. Type B modes are all modes such that when seen, a corrective action will be attempted. Another element of the management strategy which impacts the growth potential is the effectiveness of the fixes for Type B modes. The maximum reliability that can be achieved for the system is attained when all Type B modes have been seen through testing and a fix, with a certain effectiveness, has been incorporated for each mode. In this presentation, we give practical procedures for evaluating the management strategy for a system and assessing the likelihood of attaining the reliability objectives. The approach focuses attention on the impact of not fixing certain failure modes and quantifies the impact of the engineering fixes on the system reliability growth potential. These methods are useful for trade-off studies to establish a viable management strategy early in a development program so that the growth potential is sufficient to attain the reliability objectvies. Examples based on actual systems are discussed to illustrate the application of these preocedures.

A GEOMETRIC REPRESENTATION OF TAGUCHI SIGNAL TO NOISE RATIO

Khosrow Dehnad
AT&T Bell Laboratories
Holmdel, NJ 07733

The notion of quadratic loss function is used to arrive at a formal definition of Taguchi's "signal to noise ratio". It is shown that the S/N ratio can be interpreted as a measure of the angular deviation of a product/process functional characteristic from its target. Also, a geometric interpretation of the decomposition of loss into systematic and random components are presented along with the two step optimization procedure based on it.

TESTING FOR THE STAR – EQUIVALENCE*
OF TWO PROBABILITY DISTRIBUTIONS

Kalpana Kusum, Subhash C. Kochar and Jayant V. Deshpande
Department of Statistics
Panjab University
Chandigarh, India

Based on independent random samples from two absolutely continuous distributions, distribution-free as well as asymptotically distribution-free tests have been proposed for testing the null hypothesis that two distributions are identical except for an unknown scale parameter against the alternative that one is star ordered with respect to the other. These tests are based on U-statistics.

* Presented by title

PRACTICAL ISSUES IN RELIABILITY ANALYSIS

Kieron A. Dey
IIT Research Institute
P. O. Box 180
Turin Road North
Rome, NY 13440

In applying reliability and statistical process control techniques to military systems/operations, a number of practical issues arise. Based in part on the IITRI/Reliability Analysis Center, this presentation reviews some of these issues for field reliability data from both component parts and repairable systems. Some common (erroneous) practices in the reliability discipline typically used to address these difficulties are reviewed together with statistical implications and suggestions for improvement. Recent case histories will be reviewed to illustrate.

ESTIMATING JOINTLY SYSTEM AND COMPONENT LIFE DISTRIBUTIONS USING A MUTUAL CENSORSHIP APPROACH

Hani Doss*, Steve Freitag and Frank Proschan
Florida State University

Consider a coherent structure ϕ of independent components, and let F denote its life distribution. Suppose that we have a sample of independent systems, each having the structure ϕ. Each system is continuously observed until it fails. For every component in each system, either a failure time or a censoring time is recorded. A failure time is recorded if the component fails before or at the time of system failure; otherwise, a censoring time is recorded. We introduce a method for estimating F, based on the mutual censorship of the component lifelengths inherent in this model, and discuss its large and small sample properties.

* Will present paper

RELIABILITY PREDICTION AS A TOOL
FOR SOFTWARE DEVELOPMENT

Michael Dyer
IBM Federal Systems Division

Software Engineering study has demonstrated the feasibility of embedding software development and testing within a formal statistical design. With this model original software can be created with sufficient quality to forego unit debugging and software testing can be used to make statistical inference about the software's reliability in its planned operating environments. A systematic process for assessing and controlling software quality during its development can be introduced that permits a certification of a product's reliability at delivery. The certification attests to a public record of defect discovery and to a measured level of operating reliability for the software.

In this paper the basis for software reliability measurement is discussed and the role of this measurement in controlling software development is examined. The control mechanism is analagous to the statistical quality controls practiced in manufacturing processes. The use of reliability objectives in the planning and control of software development projects is also discussed.

SOME ASYMPTOTIC PROBLEMS IN RELIABILITY THEORY

J. K. Ghosh
Indian Statistical Institute
Calcutta, India

Let X_1, X_2,...,X_n be a random sample from a population with density $f(x)$ and failure rate $r(x)$. It is assumed that $r(x)$ is the first part of a "bath-tub" model. That is $r(x)$ is nonincreasing for $x \leq \tau$ and $r(x)$ is a constant for $x > \tau$.

In this paper the problem of estimating the change point τ has been considered. A special case of the model has been considered by Nguyen, Rogers and Walker (Biometrika 1985, <u>71</u>, 299-304) when

$$r(x) = aI(0 \leq x \leq \tau) + bI(x > \tau), \quad a > b$$

and mle of τ is obtained by them. Here $I(.)$ is the indicator function.

In this paper we obtain the asymptotic distribution of their estimate. In addition we obtain a number of estimators, including modification of mle, under the more general model and study their properties. Validity of the asymptotic results are checked in a number of cases using simulation.

INFLUENTIAL NONNEGLIGIBLE PARAMETERS UNDER THE SEARCH
LINEAR MODEL*

Subir Ghosh
University of California
Riverside, CA

In this paper some results useful in detecting the Influential
Nonnegligible parameters under the search linear model are
presented. An estimator of the number of nonnegligible
parameters which are significant and influential is also given.

ON A MINIMAL REPAIR MODEL AND SOME PREDICTION RESULTS

Ramesh C. Gupta*
University of Maine
Orono, ME 04469

S. N. U. A. Kirmani
University of Northern Iowa
Cedar Falls, IA 50614

In this paper we consider a non-homogeneous Poisson process in which a component is replaced by a component of equal age (instead of a new one) or equivalently, in which the component is instantaneously restored to its condition immediately prior to failure. This replacement scheme has been called as, "Minimal Repair Process" or "Hot Standby System" or "Bad as Old".

A connection between the minimal repair process and record value process is established. This connection is used to obtain some distributional and characterization results for the minimal repair process. Assuming that the lifetimes follow a two parameter exponential distribution, best linear unbiased estimators for the parameters, based on repair times, are derived. Maximum likelihood prediction and linear prediction of a future repair time X_s is considered given $X_1, \ldots X_r$ ($r < s$). Finally the mean coverage and guaranteed coverage tolerance regions for X_s are presented based on the knowledge of past repair times.

* Will present paper

FAULT TOLERANT ICs: ENDURANCE OF EEPROMS UTILIZING ON-CHIP ECC

Tim Haifley
SEEQ Technology, Inc.
San Jose, CA

Use of electrically erasable programmable read only memory (EEPROM) ICs in system applications is on the rise. EEPROMS enable the erasure and rewriting (reprogramming) of ROM data without device or PCB removal, requiring only TTL voltages. Of course, EEPROMs are non-volatile meaning that data is retained even when system power is removed. For applications requiring frequent reprogramming, EEPROM reliability can be limited by endurance, or the number of times reprogramming can be accomplished without failure. EEPROM endurance is commonly specified at 10,000 reprogram cycles. EEPROM endurance has been greatly improved by on-chip error correction coding (ECC). This results in a significantly lower failure rate for a 10,000 cycle EEPROM and makes possible a one million cycle EEPROM.

Along with a brief discussion of EEPROM technology, this paper presents an endurance model when on-chip ECC is used. This necessarily includes the effects of wafer fabrication defects which may consume some of the redundant memory cells and ultimately effect endurance (and therefore reliability) in the field.

Use of the model proves that EEPROMs with on-chip ECC should be used in those applications requiring high reliability and frequent reprogramming.

STATISTICAL PROBLEMS IN DEVELOPING COMPUTER AIDED ENGINEERING METHODS FOR DESIGNING QUALITY AND RELIABILITY INTO PRODUCTS

BY

JEFF HOOPER
AT&T BELL LABORATORY

ABSTRACT

The movement of Quality improvement activities earlier into the product realization process is one of the most important trends in Quality Control. At the same time more and more product design is being done in the computer using strategically computer aided engineering and design systems. The use of these computer aided engineering systems offers tremendous advantages over previous design methods by allowing many more design alternatives to be explored in a much shorter period of time. It is clear that methods for cost effectively designing Quality and Reliability into product must be built into computer aided engineering systems if the use of these methods is to become a routine part of the product design process.

The field of Statistics has a great deal to contribute towards computer aided engineering methods for cost effectively designed Quality and Reliability into products and processes. But to date Statisticians have done very little work in the strategically important area. In this talk I will point out several problem areas were Statisticians can have large impact on computer based methods for designing Quality and Reliability into product.

QUALITY CONTROL CHARTS
WITH POINTS REPLACED BY BOX-PLOTS

Boris Iglewicz
Department of Statistics
Temple University

An alternative to standard location/scale quality control charts
is introduced by replacing points with appropriately graphed
box-plots. Such plots are on the same scale as the original
data, making it posible to visualize the degree of compliance
with standards in addition to determining whether the process is
in statistical location/scale control. Small sample
probabilities, derived from a previous study, prove helpful in
constructing the chart. Such a simple box-plot chart provides
useful information usually obtained from several separate control
charts.

MULTIVARIATE QUALITY CONTROL IN 1986

J. Edward Jackson
Consultant

This is a tutorial paper concerned with the status of multivariate quality control at the present time. Topics will include the use of Hotelling's T^2 and its associated generalized statistics, principal components and some recently suggested techniques such as multivariate CUSUM and the use of Andrew's plots. The problems associated with multivariate acceptance sampling and acceptance control charts will also be discussed.

SYSTEMATIC ARRANGEMENTS OF TAGUCHI LATTICES

Peter W. M. John
The University of Texas
Austin, TX 78712

Factorial experiments with factors at two or three levels are important in the off-line experimentation advocated by Taguchi for modern quality improvement. He uses certain main effects plans that he calls lattices.

In most engineering experiments the engineer makes his runs consecutively, one after the other, over a period of time. During that period there may be time trends in the experimental units, which could affect the response. Daniel and Wilcoxon (Technometrics 1966) discussed the use of systematic designs, or sequences, for ordering the points of a two-level factorial experiment so that the main effects, and perhaps the two factor interactions, would be independent of linear and quadratic trends.

We show that their sequences are actually a class of foldover designs, and use this idea to construct other trend-free fractions of two level factorials. The concept of folding over is extended to experiments with factors at three levels, and, in particular, to Taguchi's L27 and L18 lattices.

STATISTICAL TECHNIQUES FOR COMBINING LABORATORY AND FIELD EXPERIMENTS FOR AN ENVIRONMENTAL STRESS MODEL OF SERIES SYSTEMS

John P. Klein*
Sukhoon Lee
Department of Statistics
The Ohio State University

Suppose that under ideal laboratory conditions we have independent life tests on the components of a series system. We also have field data on the series systems constructed from these components. We assume that under laboratory conditions the component lifetimes are exponential and that in the operating environment there is a random environmental effect which simultaneously degrades or improves each component in the system. Assuming this random environmental effect follows a gamma distribution, we obtain maximum likelihood estimators of the parameters as well as estimators based on the total time on test statistic. The problem of experimental design is also considered and suggestions for optimal allocation of resources to the lab or field experiment are made.

* Will present paper

LINKING LOR MODELS TO PROVISIONING MODELS

Melvin B. Kline
Naval Postgraduate School
Monterey, California

Many models have been developed for logistic support analysis. These include level-of-repair (repair/discard) models, spares provisioning models, and reliability and maintainability prediction models. This paper describes how level-of-repair analysis models may be used to provide inputs to provisioning models to allow optimization of both maintenance and supply resources.

ESTABLISHING SPECIFICATION LIMITS FOR RAW MATERIALS IN CHEMICAL PROCESSES BY COMBINING TRADITIONAL RSM OR EVOP WITH TAGUCHI STYLE OUTER ARRAYS

John Lawson
FMC Corporation

Specification limits for raw materials used in chemical processes are often determined quite arbitrarily. Maintaining tight specification limits may substantially increase a supplier companies cost without equal benefits to the customer company. On the other hand, large variability in raw material quality, encouraged by wide specification limits, may reek havoc in a chemical process, yet not substantially decrease the cost to the supplier.

Taguchi has shown a systematic approach, using Parameter and Tolerance Designs, to establish specification limits in a way that minimizes the total cost. This paper explores the way that RSM, 2^{k-p} designs and EVOP layouts, normally used in the chemical process industry, can be applied in Taguchi's framework of inner and outer arrays to establish specification limits for raw materials at the same time as accomplishing the traditional goal of finding the optimum process operating conditions.

ISSUES RELATED TO THE RELIABILITY
OF PRODUCTION EQUIPMENT

Robert H. Lochner, Senior Consultant
W. A. Golomski & Associates

Since production equipment is itself manufactured, it would seem
that analyzing its reliability would be no different than
analysis of airplanes, computers or other finished products.
There are, however, some distinctive features in evaluation of
production equipment reliability. Effects of production
equipment failure are typically measured in costs of downtime,
nonconforming product, failure to deliver on time, and
maintenance. A machine which needs to be stopped for a two
minute adjustment an average of once an hour would be viewed as
more reliable than equipment which fails an average of once a day
but produces a large amount of scrap when it goes down. It is
usually possible to increase reliability of production equipment
by decreasing the production rate. But again the relevant
measure of reliability is net profit rather than mean time
between failure.

Analyzing the reliability of production equipment can be
complicated by the inability to detect failure. For example, if
a rate of 0.01% nonconforming units is acceptable while 0.10% is
not, it may be difficult or impossible to detect when the rate
changes (system fails). Such undetected failures can be costly
in terms of customer dissatisfaction or rejection of manufactured
products.

In this paper several approaches to dealing with the distinctive
nature of production equipment reliability are discussed.

MODELS FOR RELIABILITY PERFORMANCE AND COSTS:
AN APPLICATION TO STRUCTURAL DESIGN ALTERNATIVES

Submitted by

Andrea L. Long

with the assistance of
J. Sterling Crandall
University of Michigan
Ann Arbor, Michigan 48109

ABSTRACT

1. Statement of the Problem

Once engineering design choices are implemented. some costs of unreliability become fixed. By building physical models with different characteristics, subjecting them to accelerated life testing, measuring engineering design and other characteristics for each model. and conducting statistical variation simulation, controllable and uncontrollable source of unreliability can be identified before the item is produced.

In this application to hiproofs, the method measures the marginal contribution of structural design alternatives, and their interactions, to the structure's reliability, measured by ultimate strength holding constant the weight. Variations in reliability costs—measured by labor time in design and production and by weight—are then modeled. Questions for structural, mechanical, or electronic prototype devices' reliability with this method include the following:

(1) What characteristics not ordinarily associated with structural percformance explain differences between models' actual reliability or ultimate strength, and the strength predicted by classical theory?

(2) What design configurations maximize reliability performance unconstrained by cost, according to computer simulations?

(3) What design configurations maximize reliability performance relative to reliability cost, according to simulations?

(4) Are there boundary values for one or more design choices which, alone or in combination, account for premature failure of the system?

(6) How much does cost. measured in labor time, increase with changes in design choices?

Using Cox proportional hazard models, structures' abilities to survive stress and survive loads is explained as a function of construction characteristics. Models' simulation outcomes are compared with those from alternative models. The marginal costs of design choicesthat have higher marginal productivity in load-carrying capacity are statistically estimated.

2. Data Used

Seventy-seven scale models of a complex, light wooden structure are characterized by weight, ultimate strength, rafter size and spacing, method of bracing, and materials employed. Other data include the time required to build the model, skill and experience of the producer(s). degree of innovativeness in design, elapsed time between completion of the model and load testing. and reinforcement type. These hedonic data are used to validate physical tests and to develop a model that would simulate the strength and the construction time cost. The coefficients on the tests measure the increment in building capacity (measured by loads to deflection, and by loads to failure); and the increment in building cost (measured by weight and labor time components of production) associated with each structural characteristic. The model is validated against a second series of 92 models.

3. Methods

Models were engineered and built by different designers to meet a set of limiting performance criteria. Among the criteria were general form, minimum strength, and type of wood. Innovation

in design was encouraged by excluding the usual or conventional solution to a major structural problem.

The physical testing procedure simulates a uniform gravity load applied at a slow constant rate. Performance of the models is physically and then statistically tested in two ways: load associated with instability or excessive deflection; and load associated with failure or collapse of the models. Sensitivity of the statistical model to "censoring" of models' survival times is examined using the second series of models.

The statistical testing procedure is threefold. First, multiple regression analysis is used to predict capacity (load to failure adjusted for weight), load to failure, and building time, as functions of design characteristics and non-structural factors. Second, maximum likelihood estimation is used to predict the likelihood of failure at a predetermined threshold. The effects on reliability performance and reliability costs of censoring at the predetermined threshold are relaxed using the second series of physical models. Third, Cox proportional hazards models are used to predict failure rates as log-linear functions of the covariates. This technique produces superior simulation results because it quantifies the relationship between survival of a structure and a set of explanatory variables, and because it takes account of censoring of those models that do not fail when subjected to the "minimum load" criterion. Then determinants of reliability "costs" — weight of materials, and labor time holding constant other inputs — are estimated as functions of design characteristics.

These methods are an advance over non-simulation-based methods that rely on case studies of real structures' performance. Unlike case study methods, variance simulation and statistical testing measure the marginal contribution of each design characteristic to reliability performance (holding constant other characteristics) and to money and time expenditures for greater reliability. The analytic models are used to simulate performance of structures with a given set of design characteristics. Results of simulation by statistical models are then validated with subsequent load testing. The ability to evaluate the statistically simulated model with new physical models is an important contribution of the research.

4. Summary of Findings

Among the first series of 77 models tested, 56 percent became unstable or deflected excessively at loads smaller than the 454 −gm- design criterion. Only 6 of the models collapsed before the 454 −gm- load was reached. On average, the models supported 34134 −gm-. Successful models (themselves weighing only 119 to 375 −gm-) supported a wide range of ultimate loads — from 45400 to 308720 −gm- (coefficient of variation = .4798).

Ultimate strength of the hiproof models statistically increases with rafter size and weight of the structure, and decreases with rafter spacing. Model-design skill increases the strength, but is less significant than the other factors. The type of materials used and reinforcement (such as bridging and corner bracing) has no effect on reliability. Type of adhesive and craftsmanship do ensure that the model reached the minimum load criterion, but the former does not significantly increase the ultimate strength of the structure beyond that point.

Hours to build each model averaged 18.46. Labor time increases significantly with inclusion of facia and corner bracing and with the use of a slow-drying adhesive; and decreased with greater rafter spacing.

The relationship between the fit and the time required to build the models is also examined. The factors or covariates contributing to the higher load-to-failure are statistically determined, and a confidence interval is constructed. The results from the statistical tests support, but are not identical with classical theory. Interaction effects between the determinants of ultimate strength

are also tested. Interaction effects between rafter size, rafter spacing, and type of sheathing are not significantly different from zero, a result that confirms the assumptions of classical theory.

5. Structural Design Implications of Simulation

This research suggests that reliability performance differences associated with structural design characteristics and production properties can be evaluated economically using variation simulation methods and statistical modeling. Computer simulation of model behavior, taking censoring of lifetimes into account, can be used to identify design and production characteristics that contribute estimable amounts to reliability performance and reliability costs. Statistical simulation based on the results of physical testing calculates the contribution of factors like rafter size and spacing in a way that is different from simulation based on classical theory. Variables dominant in classical structural theory, such as elastic modulus and moment of inertia, contribute to costs without adding to reliability performance in the statistical simulation.

Physical and statistical variance simulation and stochastic modeling techniques may provide a more efficient estimate of the effect of certain variables (like craft skill) than conventional deterministic engineering approaches. Computer simulation provides a way to estimate the probable deviation from predicted strength as the composite effect of many design parameters.

DEVELOPMENT AND ESTIMATION OF THE BESSEL-GAMMA FAILURE MODEL

Raghuram K. Machiraju
S. A. Patil
Tennessee Technological University

In this work we present a new failure model, the Bessel-Gamma
failure model (BGF). The distribution of the failure time of a
system under this model is obtained through the process of
compounding two gamma distributions. A special case of the
model, the simplified Bessel-Gamma function, can be profitably
used to characterize the failure behavior of systems whose
failure rate decreases with time. We obtain expressions for the
moments, reliability and the failure rate for the general and
special cases. Also, we determine the maximum likelihood
estimator of the reliability. Furtermore, the mean square error
and the variance of the M.V.U.E. of reliability are computed for
different sample sizes. Finally, the model is compared with the
gamma and exponential failure models.

* Presented by title

APPROXIMATE COMPUTATION OF POWER GENERATION SYSTEM RELIABIITY INDEXES

M. Mazumdar and C.K. Yin
Department of Industrial Engineering
University of Pittsburgh
Pittsburgh, PA 15261

Reliability models play an important role in the determination of the generation reserves of an electric power utility company and of its expected operating cost. These models are used to compute the risk of system load loss and the capacity utilization ratios of different units within the system. Computation of these indexes usually require the evaluation of the distribution function of the sum of a large number of discrete random variables with different distributions. Exact methods for computing these distributions prove computationally unfeasible for routine utility operations. We have earlier reported (1) on the use of Esscher's transform in providing fast and accurate approximations to the reliability measures for a single generating system. This paper extends this work by applying a bivariate version of Esscher's transform to the computation of the reliability indexes for an interconnected system consisting of two separate generating networks with correlated load. Numerical results are given showing the accuracy of this approximation scheme.

REFERENCE

(1) M. Mazumdar and D.P. Gaver (1984), "On the Computation of Power-Generating System Reliability Indexes," Technometrics, Vol. 26, 173-185.

HAZARD FUNCTIONS AND GENERALIZED BETA DISTRIBUTIONS

James B. McDonald and Dale O. Richards*
Brigham Young University
Provo, Utah

This paper considers the behavior of the hazard functions of the
Generalized gamma, and beta of the first and second kind. The
hazard functions are seen to include "n", "u" shaped, constant
and strictly increasing as well as strictly decreasing hazard
functions. By considering the generalized distributions a
unified development for such distributions as Beta type 1, Beta
type 2, Burr types 3 and 12, Power, Weibull, gamma, F, Lomax,
Fisk, Uniform, exponential and Chi Square are then included as
special cases. These results are conveniently summarized in
three figures.

*Will present paper

RESEARCH OPPORTUNITIES IN SOFTWARE RELIABILITY

John D. Musa
AT&T Bell Laboratories
Whippany, NJ 07981

The field of software reliability measurement is viewed with
respect to present research needs and opportunities. The role of
software reliability measurement in the development and operation
of computer-based systems is discussed. We will examine the
steps in applying these techniques in order to understand the
process. Then the state of the art will be evaluated, and we
will point out areas where further research is particularly
needed.

NONPARAMETRIC PROCEDURE FOR SELECTING THE LEAST
NBU POPULATION; LARGE SAMPLE APPROACH

Dong Ho Park* and K. M. Lal Saxena
University of Nebraska
Lincoln, NE

Let $\pi_1, \ldots, \pi_k$ be k independent populations with continuous distributions $F_1, \ldots, F_k$, respectively. Hollander and Proschan (AMS, 1972) proposed $\theta_i = \iint \bar{F}_i(x + y)\, dF_i(x)\, d F_i(y)$ as a measure of the NBU-ness of the distribution F_i and used it to develop a test of exponentiality versus NBU alternatives. In this report the k populations are compared in terms of θ_i and we are interested in selecting the population with the largest θ value which is, we define, the least NBU population. We do not assume that the k populations are necessarily NBU and thus another goal is to select a subset of the k populations which contains all nonexponential NBU populations. These procedures are based on the U-statistics estimators of $\theta_1, \ldots, \theta_k$ and their large-sample properties.

* Will present paper

AVERAGE RUN LENGTH COMPARISONS OF TWO MULTIVARIATE CUSUM CHARTS FOR CONTROLLING THE MEAN OF MULTIVARIATE NORMAL PROCESSES

Joseph J. Pignatiello, Jr.*
Systems and Industrial Engineering
The University of Arizona
Tucson, AZ 85721

George C. Runger
General Products Division
IBM
Tucson, AZ 85744

We propose two distinct multivariate cusum charts for controlling the mean of a multivariate normal process. The performance of the two charts is compared by simulating multivariate normal processes and estimating the average run length curve for each chart. The average run length curves of these two charts are also compared to the average run length curves for multiple univariate cusum charts, multiple univariate $\overline{X}$-control charts and a X^2-control chart. We discuss the prospects of a combined multivariate cusum/Shewhart chart. Average run length curves are presented.

* Will present paper

OPTIMUM REPLACEMENT OF A SYSTEM SUBJECT
TO SHOCKS AND A MATHEMATICAL LEMMA

Prem S. Puri
Purdue University
Indiana

Harshinder Singh*
Panjab University
Chandigarh, India

Let a system be subject to shocks which occur randomly over time. Let $N(t)$ denote the number of shocks occurring in $[0,t]$. It is assumed that the system needs replacement after it has functioned for a random length of time τ, a moment of a major failure, which is a stopping time with respect to the process $\{N(t), t \geq 0\}$. The costs we consider are due to shocks, maintenance and replacement. Again it may be economical to replace the system at time min (t,τ) prior to its failure, for some fixed but optimally chosen t. Based on cost considerations we introduce an optimality criterion which we then use to find an optimal time t_0. In the process, we prove a general mathematical lemma which helps in arriving at the optimal time, for general classes of processes $\{N(t)\}$, stopping times τ and the cost structures involved. A discrete time version of the lemma is also given.

The present work was inspired by two recent pieces of work involving shock models by Boland and Proschan (1982, 1983). However for previous other similar work, the reader may also refer to Taylor (1975), A-Hameed (1977), A-Hameed and Shimi (1978), Zuckerman (1978, 1980), Feldman (1976, 1977a, 1977b), Boland (1982), Tilquin and Cleroux (1975) and Nakagawa (1981).

A typical optimization problem that appears in most of these papers involves minimization of a ratio of two known functions with respect to their common argument. In section 2, we prove a basic mathematical lemma which solves this problem subject to certain conditions on the two functions. Our lemma is fairly general and covers many cases solved in the literature. In particular it applies to the models considered by the above authors. For convenience of presentation we shall consider, in some detail, a generalized shocks-based model involving a stopping time τ, as described below.

Suppose a new system is subject to shocks which occur randomly over time. Let $N(t)$ denote the number of shocks occuring in $[0,t]$. The random process $\{N(t), t \geq 0\}$ is assumed to be a separable point process with $N(0) = 0$, $N(t) < \infty$, for all $t \geq 0$ a.s. and right continuous sample paths with unit steps at $0 < \tau_1 \leq \tau_2 \leq \ldots$, with $\tau_0 = 0$. As a rule, it is assumed that the system needs replacement after it has functioned for a random length of time

τ, a stopping time with respect to the process $\{N(t), t \geq 0\}$. In many situations, shocks may be interpreted as small, reparable breakdowns of the system and τ is the time when it undergoes a major irreparable breakdown needing a replacement. When the costs that are involved are due to shocks, maintenance and replacement etc., it may be economical to replace the system at time min (τ, t) for some fixed but optimally chosen t. One of the objectives of the present work is to define an appropriate optimality criterion which is then used to arrive at an optimal time, t_0.

Generally the stopping time τ is beyond our control. For instance, when the arrivals of shocks are interpreted as occurrences of small reparable break-downs of the system, the risk of having a major breakdown needing replacement may depend upon the number $N(t)$ of the reparable damages. For example, when the system cannot stand more than k small breakdowns after which it then has to be replaced, $\tau = \tau_k$. Another example is a system consisting of k components running in parallel. The system is considered to have failed only when all the k components stop functioning. If we interpret jth shock as the failure of the jth components, $j = 1, 2, ..k$, then $\tau = \tau_k$. Other examples are situations where each shock may cause a random damage to the system and τ is the time the cumulative damage caused by the shocks exceeds a fixed (or a random) threshold.

In the above examples τ is dependent upon the process $N(t)$. However, in some situations τ could be considered independent of the process $N(t)$. For instance, consider a system which is functioning with the help of electric power. Shocks may be interpreted as minor reparable breakdowns due to wear and tear. The system may get totally destroyed after it receives a rather high power surge. Here τ, the time of such an eventuality may be approximately independent of the process $N(t)$. Finally, in the event no such risk that we have prepresented by τ exists, we take $\tau = \infty$.

ESTIMATION OF THE INTENSITY
FUNCTION OF A WEIBULL PROCESS

Steven E. Rigdon*
Monsanto Research Corporation
Miamisburg, OH 45342

Asit P. Basu
University of Missouri
Columbia, MO 65211

Nonhomogeneous Poisson processes are often used to model the failure times of systems which are repaired upon failure. A popular parametric form of the nonhomogeneous Poisson process is the Weibull process. Estimation of the value of the intensity function at the conclusion of a period of data collection is often important. For both the failure truncated case and the time truncated case, several classes of estimators are suggested. Within these classes, reasonable estimators are suggested and are compared with the conditional maximum likelihood estimator. Expressions for the bias and mean squared error are derived, and these expressions were computed for several different values of parameters to allow comparison between the estimators.

* Will present paper.

MEASURING VARIATION FOR QUALITY CONTROL APPLICATIONS

David M. Rocke
University of California
Davis, CA

This paper uses the methodology from a previous paper ("Robust Statistical Analysis of Interlaboratory Studies," Biometrika, 1983) to investigate the effect of outliers on variation measures. Applications are considered on control charts and in Taguchi designs.

ACCELERATED LIFE TESTS WITH MULTIPLE STRESSES *

Anthony A. Salvia
The Pennsylvania State University
The Behrend College
Erie, PA 16563

With high reliability devices, it is often necessary to conduct accelerated life tests in order to obtain times to failure. In recent years there has been considerable progress in developing appropriate experimental designs for a single accelerating factor. Here, we describe some simple designs that are useful in the case of several accelerating factors. The analyses employed require complete, i.e., noncensored, measurements. We discuss briefly some of the problems associated with incomplete experiments.

* Presented by title

STATISTICS - A TOOL FOR QUALITY AND PRODUCTIVITY IMPROVEMENT

S. Sengupta
Honeywell, Defense Systems Division
Minnetonka, MN

A quality and productivity improvement program must utilize statistics as a basic process management tool. In the defense systems division of honeywell, there is a renewed interest in the use of statistics for the product and process improvement.

Implementation of these techniques calls upon a well structured training program for the workforce.

Rudimentary training in statistics for the workforce is being pursued to enhance the understanding of fundamental concepts behind the process and process variation.

Training program for the engineers is being revised and concepts of the topics such as the statistical process control, design of experiments, acceptance sampling and reliability are being included.

Implementation of these techniques to improve the process is being initiated by forming the process control and other teams. Emphasis on product design, reducing variability of the process are some among the priorities.

Productivity measurements are being formulated and efforts are in place to implement these.

SOFTWARE PRODUCTIVITY MEASUREMENT

Sailes K. Sengupta*
Sushovan Sen
South Dakota School of Mines & Technology

Measurement of software productivity is an important tool to aid
in the software development and maintenance process for producing
high quality software. Productivity measurement refers to the
relationships between various inputs and outputs in relation to
computer software production. Properties of any expression of a
program that are capable of being counted or measured have been
termed as software metrics in Software Science. These metrics
have been used to measure productivity. Ratios of output to
input in relation to a software project undertaken by South
Dakota School of Mines and Technology Computer Science majors
have been analyzed. The paper aims at providing a group of
productivity measures in relation to actual project data using
multivariate statistical methods. The important variables
contributing to software productivity have been identified
resulting in a core set of objective productivity measures.

*Will present paper

CUMULATIVE DAMAGE THRESHOLD CROSSING MODELS

J. Sethuraman* and Thomas R. Young
Florida State University

We describe two general cumulative damage threshold crossing models for survival distributions. Large deviation and moderate deviation results in probability theory provide the necessary limit theorems to derive these new classes of survial distributions. These new survival distributions give superior fit to actual data when composed with the 3-parameter Weibull.

* Will present paper

THE INTERRUPTED REVIVAL PROCESS RELIABILITY MODEL
FOR A MAINTAINED SYSTEM

Michael Tortorella
AT&T Bell Laboratories
Holmdel, NJ 07733

The purpose of this talk is to introduce a new reliability model
for a maintained system. This is the Interrupted Revival
Process, which models the reliability process (the sequence of
alternating operation and repair times) of a piece of equipment
or a system by a sequence of time intervals alternately drawn
from a revival, or relevation, process (the operation times) and
a renewal process (the repair times). Quantities of interest in
such reliability process models include the expected number of
failures in a given time interval, and the probability that the
equipment is operating at a given time (the pointwise
availability). The talk includes derivations of equations for
these quantities of interest, the solutions of these equations,
and the asymptotic behavior of the solutions.

The scope of the talk includes a careful description of the model
and its relation to the operational situation being described.
The relation of the interrupted revival process to other
stochastic processes is established. We introduce the notion of
the "revival agrument" which plays a role in revival and
interrupted revival processes similar to that played by the
renewal argument for renewal processes. In particular, this
notion allows us to formulate integral equations of a special
type, called (by analogy with the renewal process case) integral
equations of revival type, for various functions on the revival
and interrupted revival processes. We give solutions to these
equations in the cases that are of most practical interest. The
revival argument and its consequences are also useful in gaining
insight into the structure of the revival and interrupted revival
processes. We analogize, compare, and contrast freely with the
more familiar renewal and alternating renewal processes to
clarify and solidify the material. The talk concludes with a
chart summarizing the analogies and points of contrast between
the renewal and revival process models.

PARAMETER AND TOLERANCE DESIGN IN QUALITY DESIGN

A. Winterbottom
The City University
London, England

Parameter and Tolerance Design are illustrated by the analysis of data from two examples. The first example is used to show how response surface methodology can be used to identify Taguchi's signal and control factors in parameter design.

The second example uses simulation methods in conjunction with experimental design to explore the variability of response in tolerance design. Incorporating a cost model for tolerances allows variance reduction to be effected in an optimal manner.

BAYESIAN TEST DESIGN FOR BERNOULLI PROCESSES - AN APPLICATION

Major Buddy B. Wood
Air Force Center for Studies and Analyses
Fighter Division
The Pentagon 20330

Reliability test programs associated with military systems are structured in a sequential fashion to (1) formally qualify the design of the system, (2) demonstrate operational capabilities under realistic environmental conditions, and (3) prevent degradation of these capabilities during production and deployment. With the ever-present pressures of cost and schedule what they are today, considerable attention is being given to using reliability data from one test program to complement results of successive tests. In this way the entire test program is viewed as a single thread rather than as a series of separately conducted and reported events. Unfortunately, without recognition of an established scientific method for combining data from several test programs, past attempts to implement this approach have been viewed with considerable skepticism.

Much work has been done in the reliability community to fill this void for continuously operating systems such as avionics, communications, ground electronics, and radar. For example, the inverted gamma probability distribution has been used to model the average life for systems with exponential failure times. Data from preliminary tests is used to construct the prior distribution, and the posterior distribution is updated as testing progresses. Testing usually ceases when the confidence in test conclusions reaches some specified threshold.

In this paper a similar approach is taken for systems which are not continuously operating, such as missiles, bombs and fuzes. These systems are moving to the forefront in development priorities, being viewed as cost effective force multipliers for our delivery systems. When the Bernoulli process is an appropriate model for these systems, the Bayesian scheme may be used to design test plans to meet specified values of producer's and consumer's posterior risks. Results are provided in tabular form for easy use by reliability practitioners.

THE USE OF MULTIVARIATE CONTROL CHARTS

William H. Woodall
The University of Southwestern Louisiana

A review is given of various types of multivariate control charts
and a criterion is given for the comparison of their statistical
performance. The importance of a clear interpretation of an out
of control signal is stressed. It is shown that the current
economic methods of designing control charts often result in
charts with very poor statistical performance.

AN INVESTIGATION OF PARAMETER DESIGN OPTIMIZATION

C. F. Jeff Wu
University of Wisconsin
Madison, WI

In robust product design one would like to find levels of the control factors under which the product performs stably over a range of values of the noise factors, thus resulting in the improvement of its quality. This problem formulation was introduced to the West by G. Taguchi. The methods he proposed make use of orthogonal arrays. His methodology contains elements that can be greatly improved. In several cases it leads to inferior parameter designs. Our study focuses on the following aspects: (i) use of orthogonal arrays for design optimization versus classical optimization, (ii) SEL, a new method for design optimization, and (iii) main-effect analysis. These points will be illustrated by real examples on the design of a heat exchanger, an OTL circuit, and a power source circuit.

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